Thermo-Sensing Apparel for Individuals with Paralysis

Paige Schiebel, Myles Cline, Holden Martin
Biomedical Engineering
Advisor: John Patton

Motivation

Adaptive athletes, or athletes with physical or intellectual disabilities, are at increased risk for frostbite due to impaired sensation and disrupted thermoregulatory processes [1]. Frostbite is a dangerous and potentially fatal condition that may occur when ambient air temperatures reach 32°F and below [2]. The condition becomes fatal when blood begins to crystalize at 24.8°F [2]. The risk of acquiring frostbite is a large concern for adaptive athletes and may deter these individuals from participating in winter sports, such as skiing [3].

The aim of the thermo-sensing apparel project was to provide peace of mind and reduce the incidence of frostbite in the adaptive athlete population by developing a device capable of identifying and alerting individuals of dangerous skin temperatures.

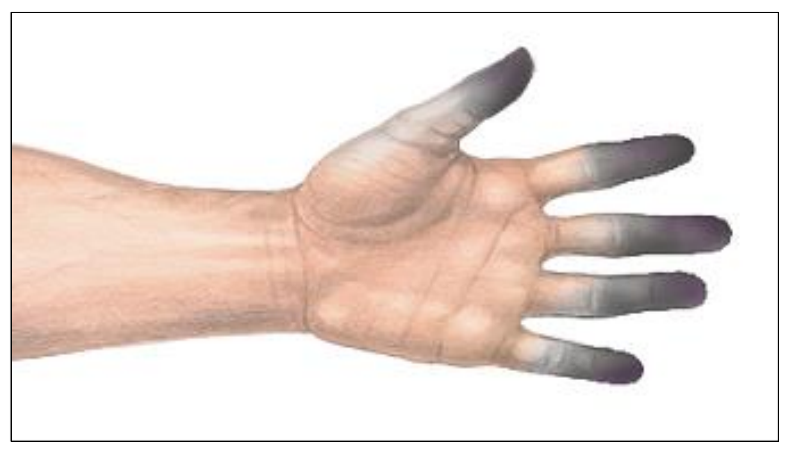

Figure 1: Frostbite of fingers [4].

Figure 2: Adaptive athlete using a bi-ski.

Thermo-Sensing Apparel Device Overview

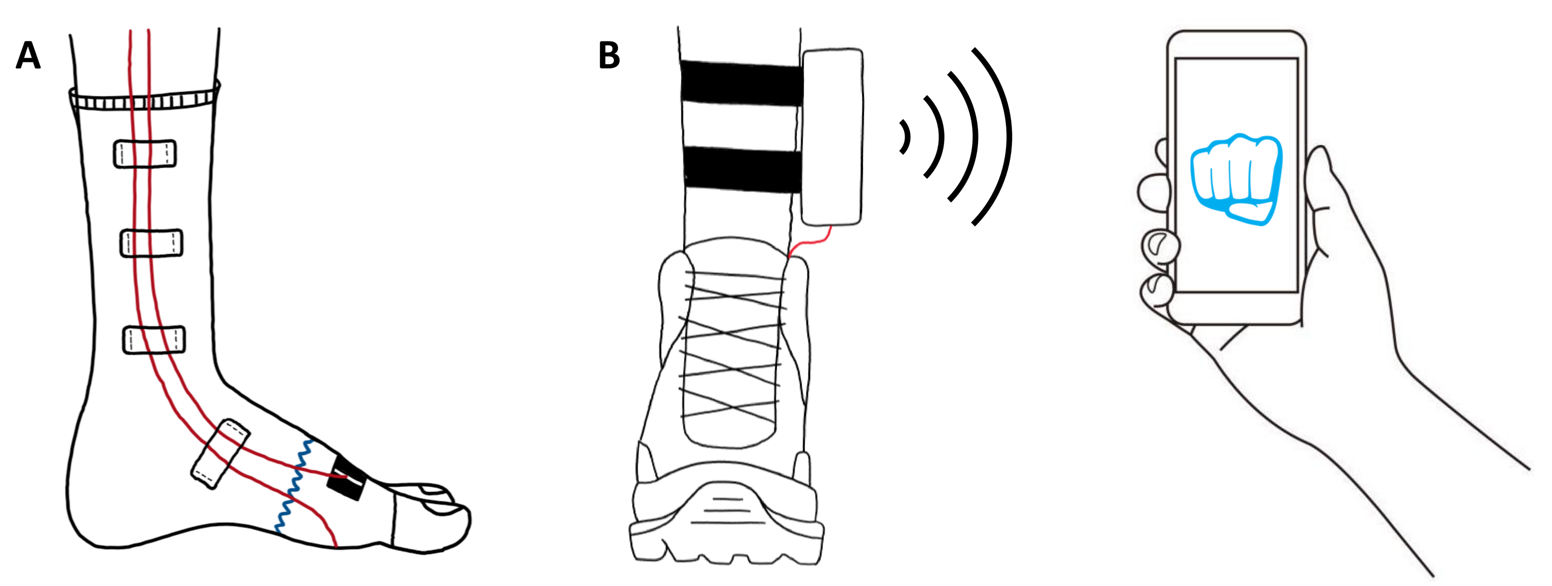

Figure 3: (A) Two temperature sensors are wired through elastic channels and attached to the custom sock via Velcro. (B) The device straps to the user's leg via Velcro straps. Temperature signals are processed, and alerts are sent to the user's cell phone via Bluetooth Low Energy, which are received via the Bluetooth reader app, LightBlue®.

Device Performance

Table 1: Overview of device performance specifications determined via testing.

Technical Specification	Value
Battery capacity	~ 108 hours
Temperature operating range	≥ 6°F
Temperature alert rate	2.5 minutes
Margin of error	± 2°F
Central unit weight	1.12 lb
Bluetooth signal range	212 ± 39 ft
Medical device drop test	Passed
Comfortability	4 out of 5 (Likert Scale)
Time required to don	≤ 7 minute

Circuit and Code Development

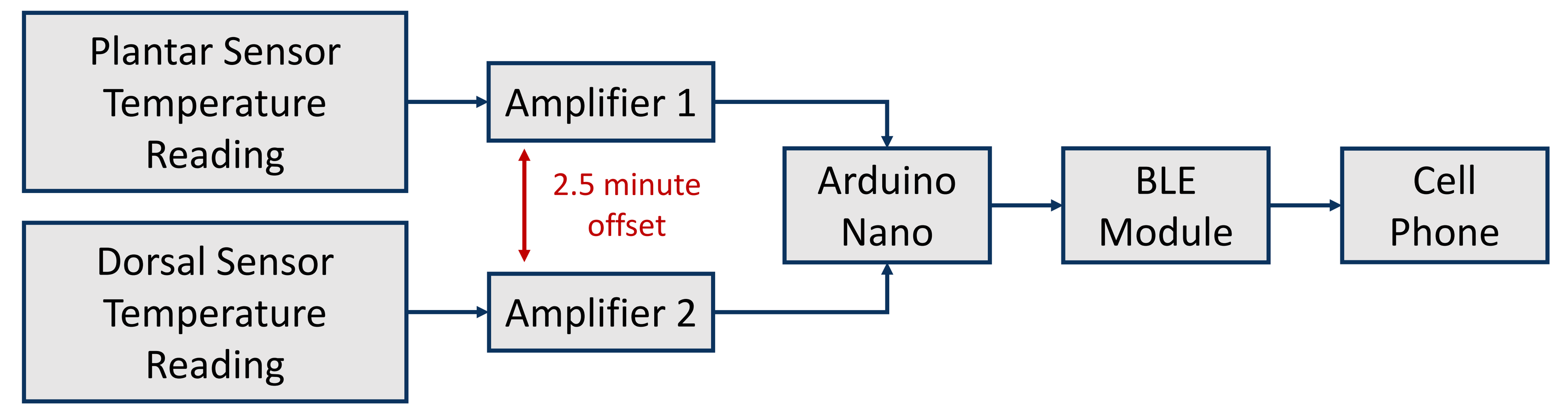

Figure 4: The device sends temperature alerts, alternating between the plantar and dorsal sensors, to the user every 2.5 minutes. The signal pathway includes two amplifiers to reduce signal noise and increase temperature accuracy, a microprocessor, and a Bluetooth Low Energy module to send temperature alerts to the user's cell phone.

Figure 5: All electronic components are soldered to a custom-printed circuit board (PCB). The Arduino Nano receives power from a power bank battery. The green LEDs draw current to ensure the battery pack remains on.

Alert Rank	Temperature Alert Begins
Safe Alert	>52°F
Low Risk Alert	52°F
Medium Risk Alert	49°F
High Risk Alert	46°F
Highest Risk Alert	≤43°F

Table 2: Highest risk alert temperature was determined via an ice bath test. Results indicate a 9°F difference between the toes and the sensor location. Device inaccuracy of 2°F was also accounted for in the threshold.

Electronic Case Development

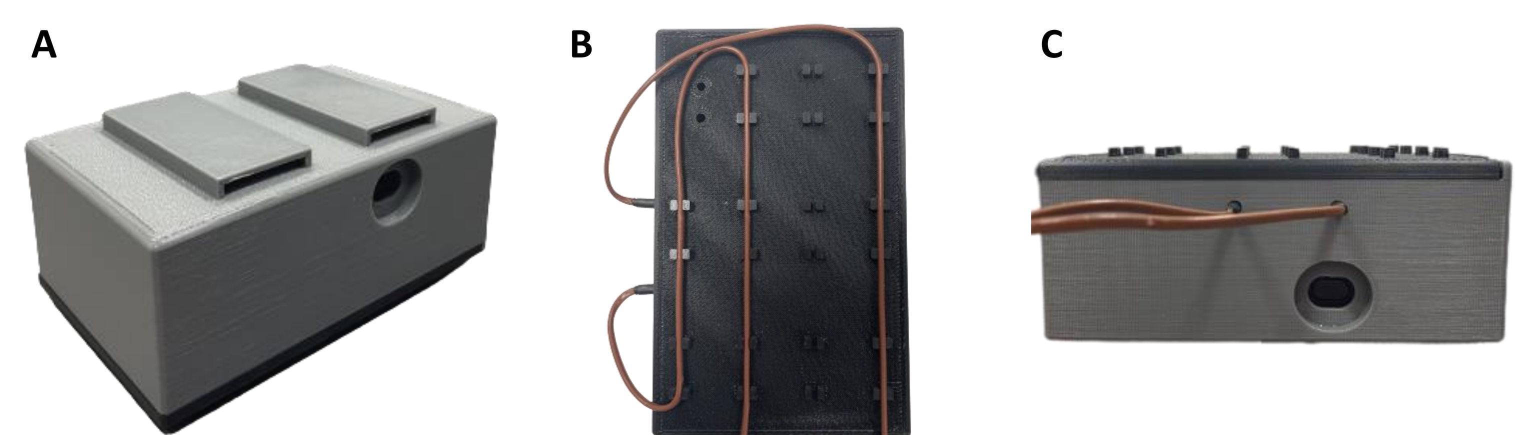

Figure 6: The 3D-printed PLA electronic case houses and protects the internal circuitry. (A) Straps for Velcro slots located on the back of the case and charging port access. (B) Wire holders, located on the top of the case, allow for wire length customization. (C) Power button access and temperature sensor exit holes on the side of the case.

Wearable Development

Table 3: Custom sock sizing chart.

Women's Shoe Size	Men's Shoe Size	Stitching Color
8-10	7-9	Red
10-12.5	9-11	Blue
10-12.5 wide	9-11 wide	Purple
12.5+	11+	Green

Figure 7: Four custom socks were hand-sewn to ensure adequate fit for various users. Four elastic wire channels line the medial side of the sock to allow for wire securement and wire length customizability. Two sensor slots are located on the dorsal and plantar sides of the sock. Sensors attach to Velcro inside the sock to maintain sensor-skin contact.

Protective Case Development

Figure 8: The protective case was developed to provide insulation and shock absorption for the device. Neoprene was selected for superior waterproofing and insulating properties. Slots are located on the back of the protective case to allow for Velcro strap **attachment. The temperature sensors exit the protective case through a hole on the bottom. Drop testing was conducted and device remained functional, thus passing the drop test.**

Carrying Case Development

Carrying case components:

- User manual
  - Demonstration video
  - Feedback survey
- Device charging cord
- Wall adapter
- Three Velcro strap sets
- Electronic case
- Protective case

Figure 9: The device carrying case provides protection to the device when not in use.

Conclusion

- Device achieved objectives set forth by the customer and design team.
- Based on initial customer feedback, the thermo-sensing apparel device has successfully met the thermo-monitoring needs of adaptive athletes.

"[The device] has really, truly got the potential to help a lot of individuals. [….] When [I'm] out there [skiing], knowing what the temperature is of my foot is one less thing that I have to worry about" – Bill, Adaptive Athlete

Figure 10: Dave, Adaptive Athlete

Acknowledgments

The thermo-sensing apparel senior design team would like to thank Dan Loch and Adaptive Adventures for project support, BAE Systems for project funding and mentorship, and Dr. John Patton for project guidance.

References

[1] K. D. Schmidt and C. W. Chan, "Thermoregulation and fever in normal persons and in those with spinal cord injuries," *Mayo Clinic Proceedings*, vol. 67, no. 5, pp. 469–475, 1992.
[2] B. M. Nagpal and R. Sharma, "Cold injuries: The chill within," *Medical Journal Armed Forces India*, vol. 60, no. 2, pp. 165–171, Jul. 2011.
[3] D. Loch, P. Schiebel, M. Cline, and H. Martin, "Discussions with Dan and Adaptive Athletes," 07-Oct-2022.
[4] K. D. Schmidt and C. W. Chan, "Thermoregulation and fever in normal persons and in those with spinal cord injuries," Mayo Clinic Proceedings, vol. 67, no. 5, pp. 469–475, 1992.